FIG. 1

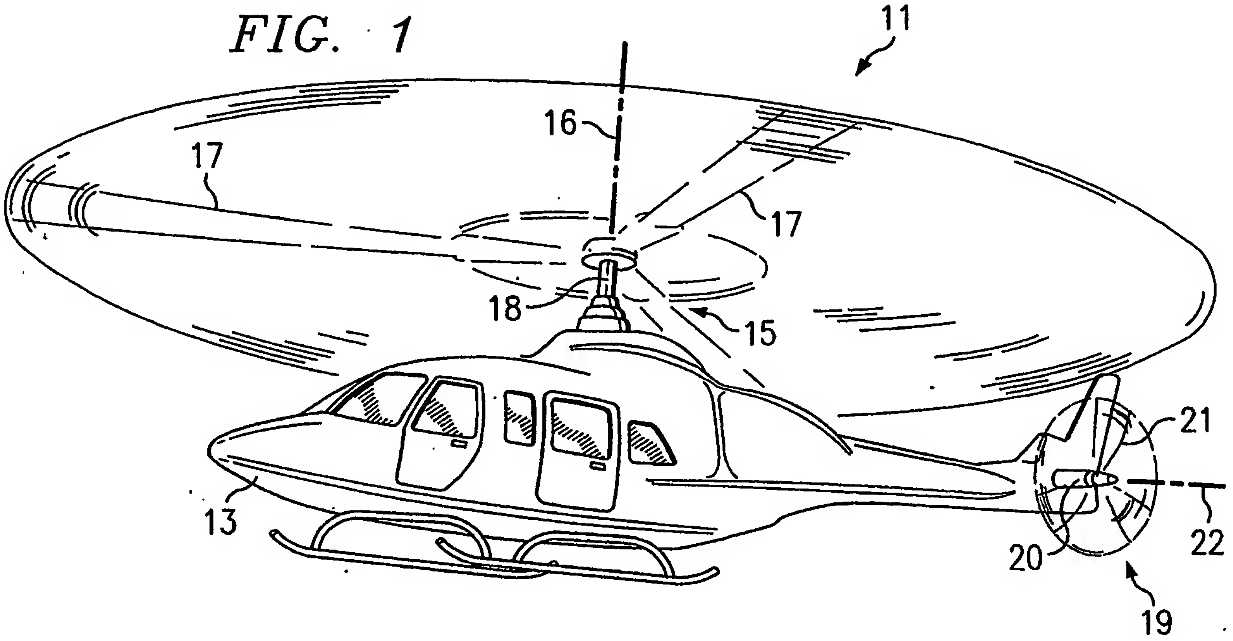
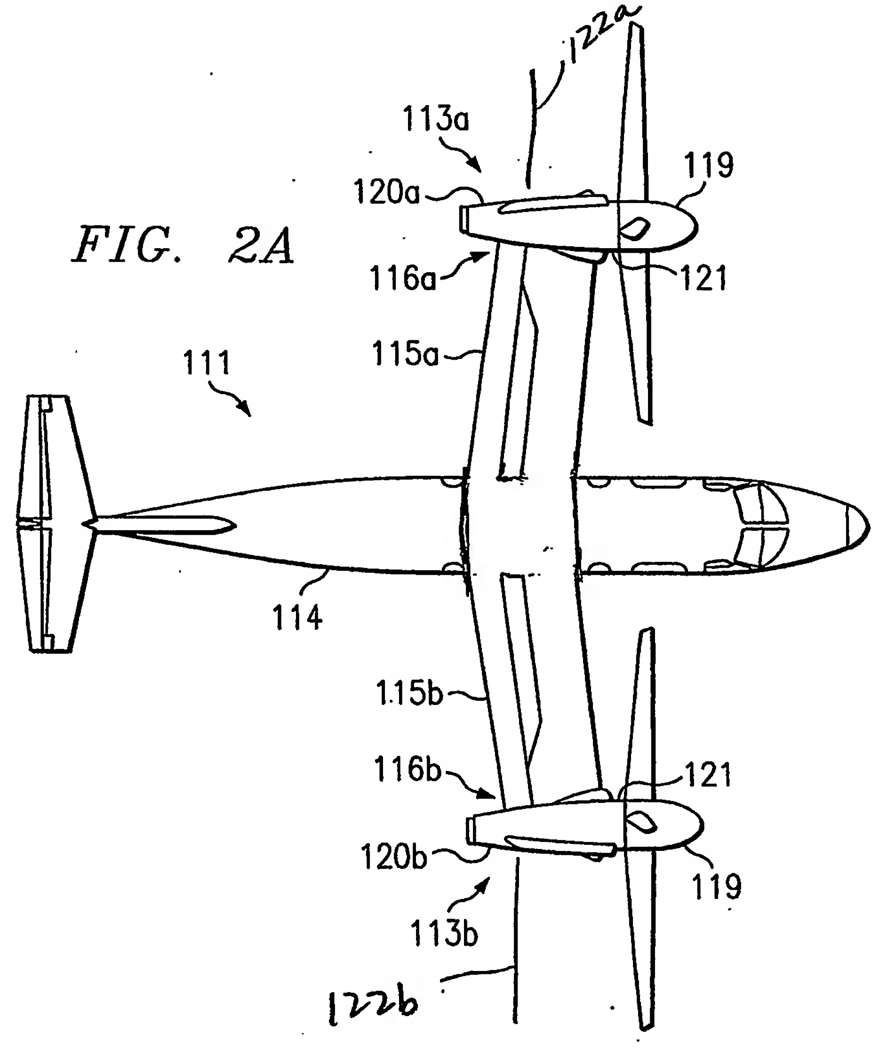


FIG. 2A


1.15b

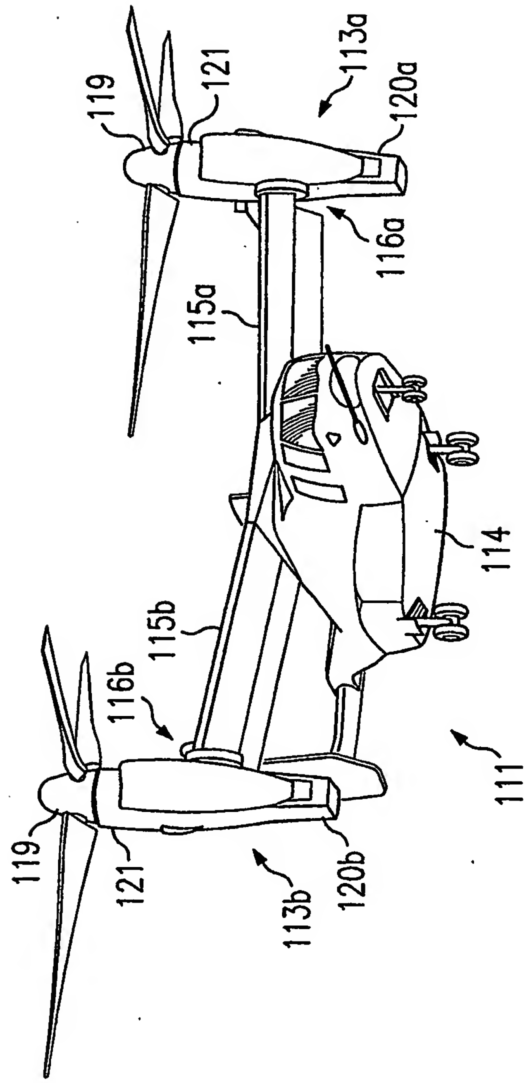


FIG. 2B

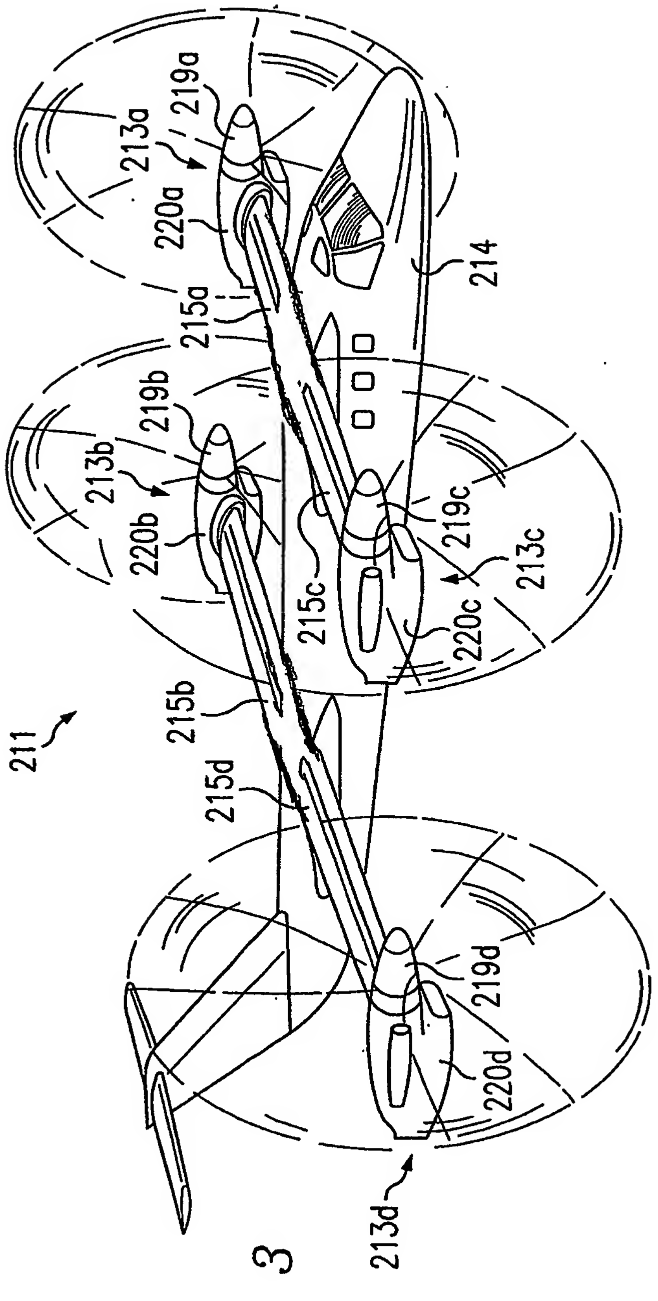


FIG. 3

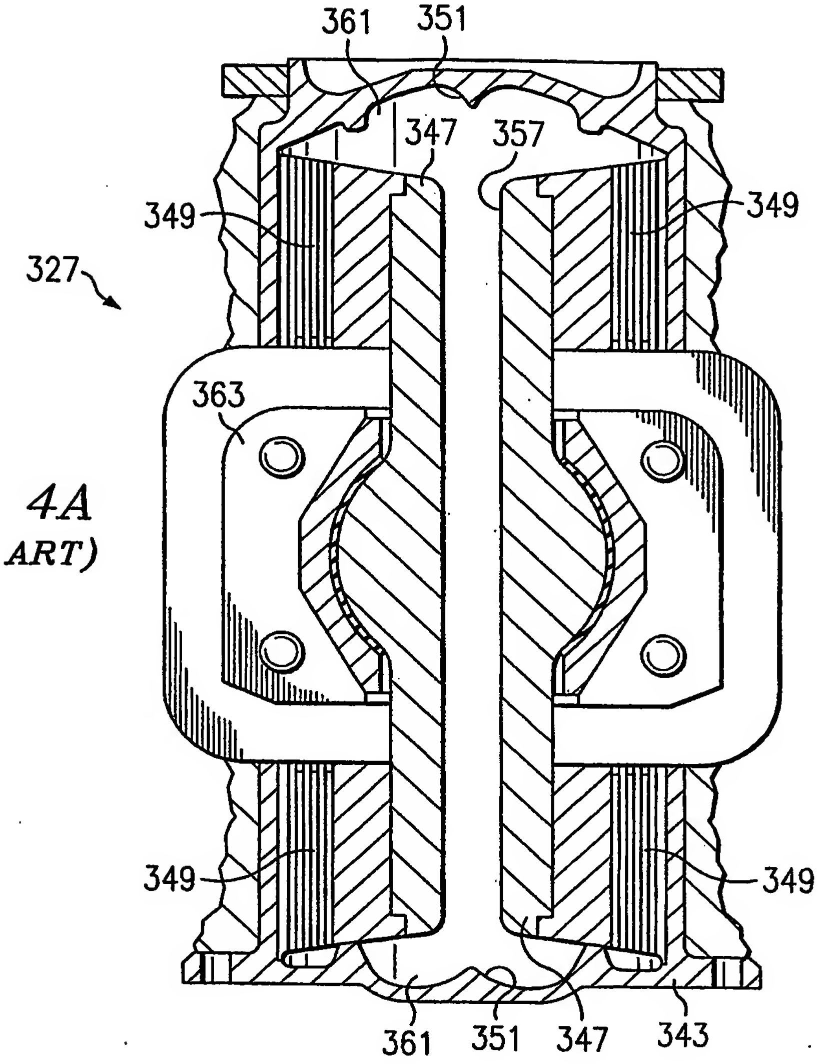

361
351
347
357
349
349
327
363
349
349
361
351
347
343

FIG. 4A
(PRIOR ART)

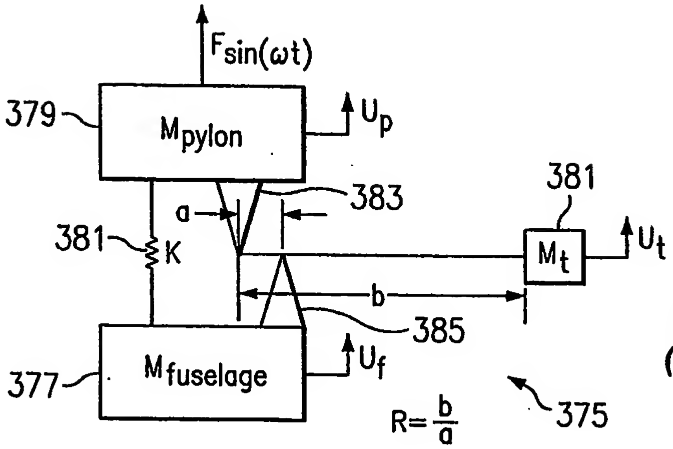

Fsin(ωt)
379
Mpylon
Up
a
383
381
Mt
Ut
381
K
b
385
377
Mfuselage
Uf
R= b/a
375

FIG. 4B
(PRIOR ART)

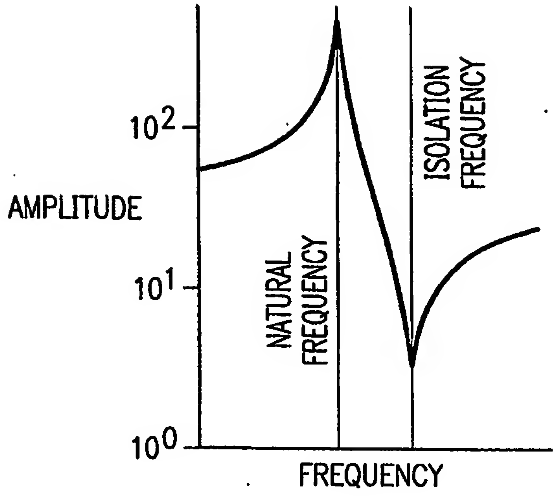


FIG. 4C
(PRIOR ART)

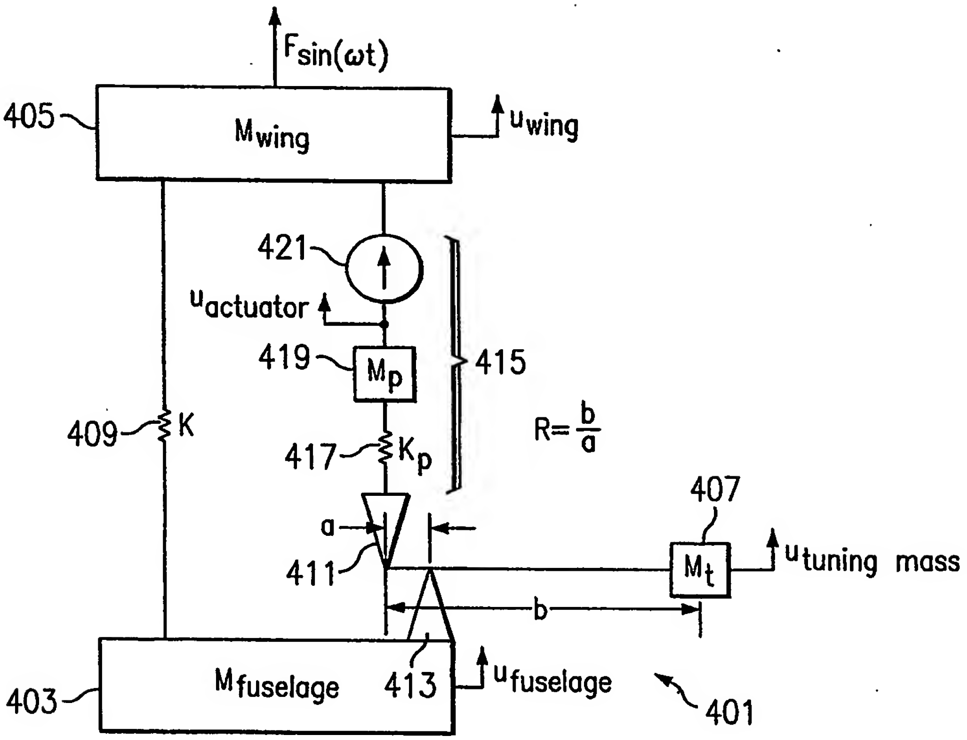

$F_{\sin(\omega t)}$
405
M_{wing}
u_{wing}
421
$u_{actuator}$
419
M_p
415
409
K
417
K_p
$R=\frac{b}{a}$
407
a
411
M_t
$u_{tuning\ mass}$
b
$M_{fuselage}$
413
$u_{fuselage}$
403
401

FIG. 5A

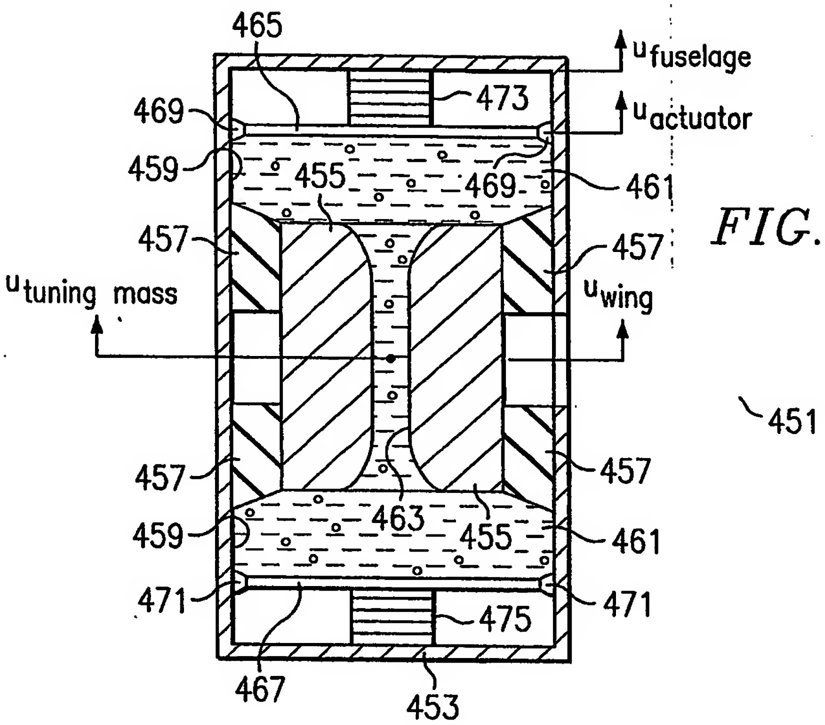

u fuselage
u actuator
u tuning mass
u wing

FIG. 5B

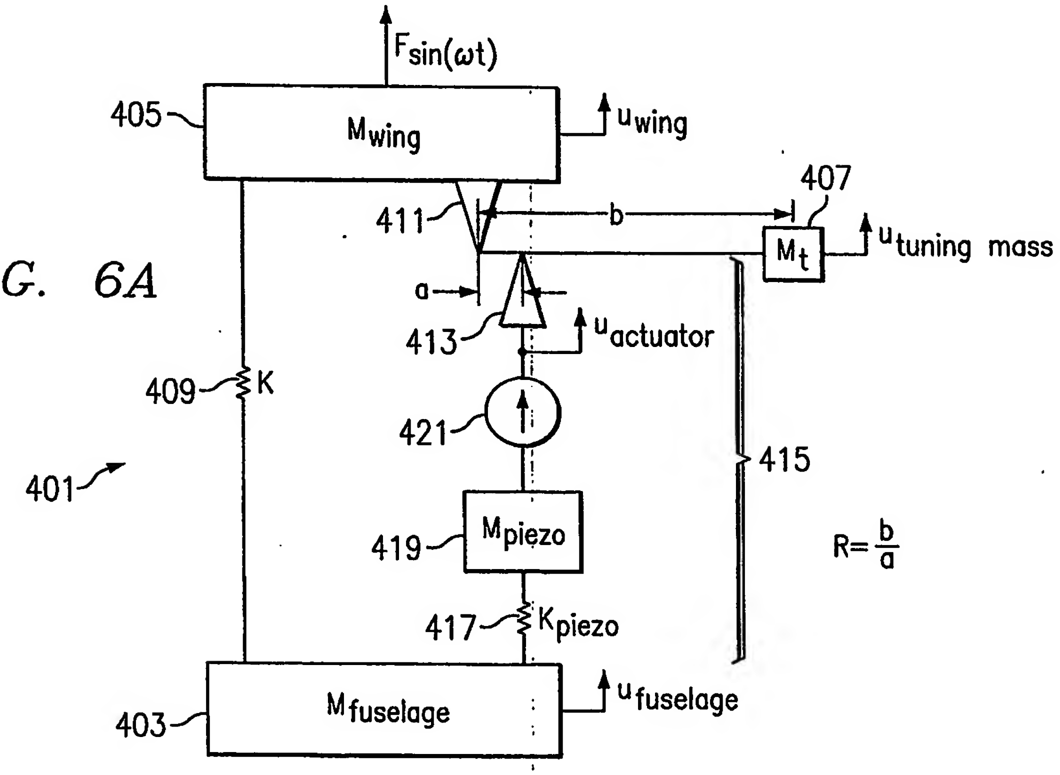

F sin(ωt)
405
M wing
u wing
407
411
b
M t
u tuning mass
a
413
u actuator
409
K
421
415
401
419
M piezo
R= b/a
417
K piezo
403
M fuselage
u fuselage

FIG. 6A

FIG. 6B

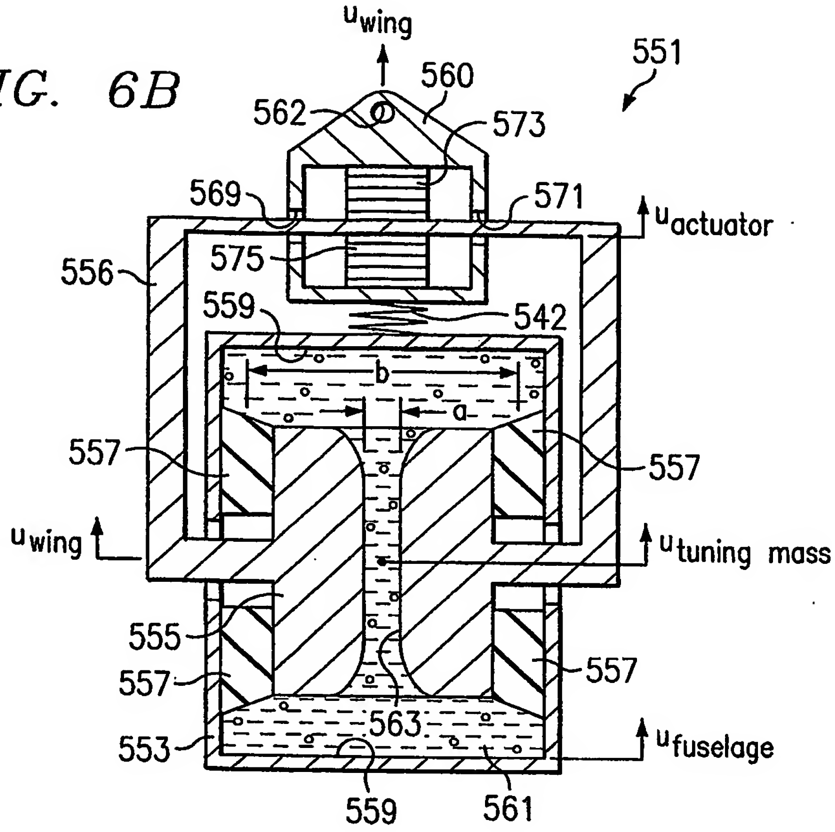

u wing
551
560
562
573
569
571
u actuator
556
575
559
542
b
a
557
557
u wing
u tuning mass
555
557
557
563
553
u fuselage
559
561

FIG. 7A

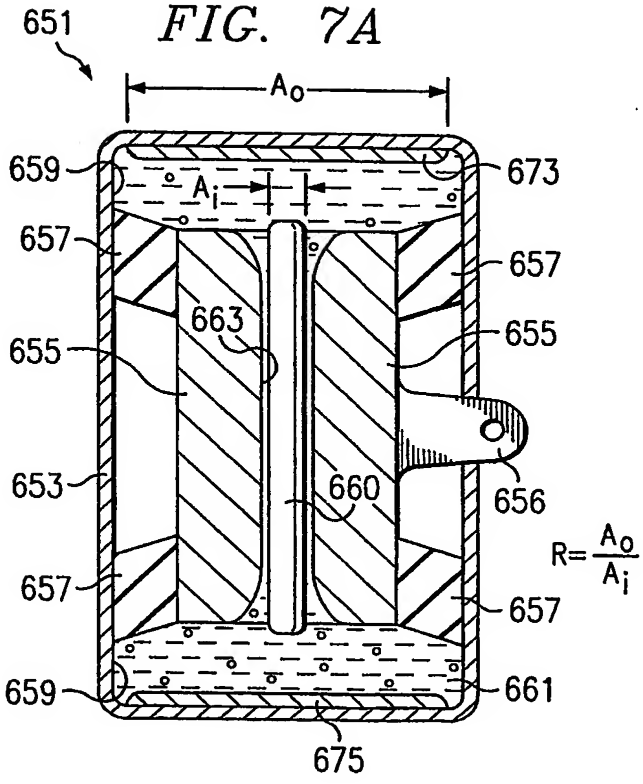

651
A o
659
A i
673
657
657
663
655
655
653
660
656
R= A o / A i
657
657
659
661
675

FIG. 7B

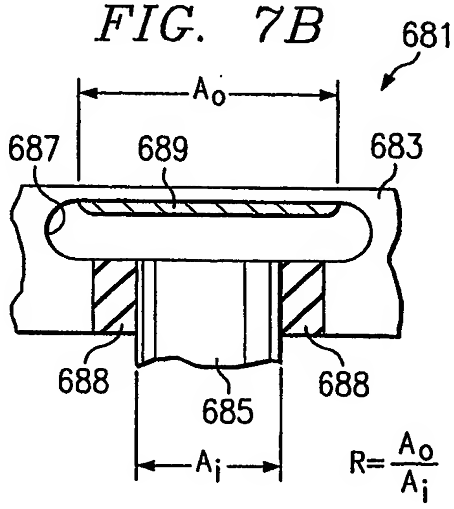

681
A o
687
689
683
688
688
685
A i
R= A o / A i

FIG. 7C

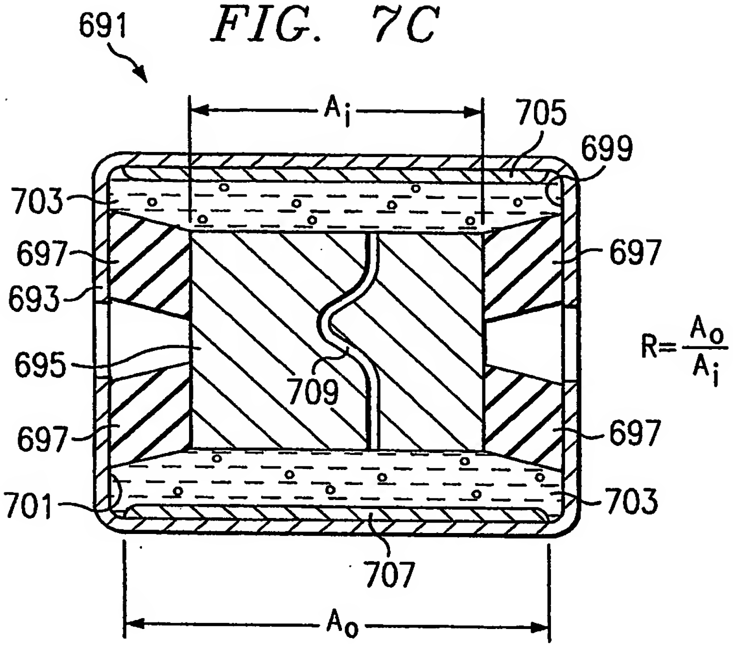

A_i
A_o
$R=\frac{A_o}{A_i}$

FIG. 7D

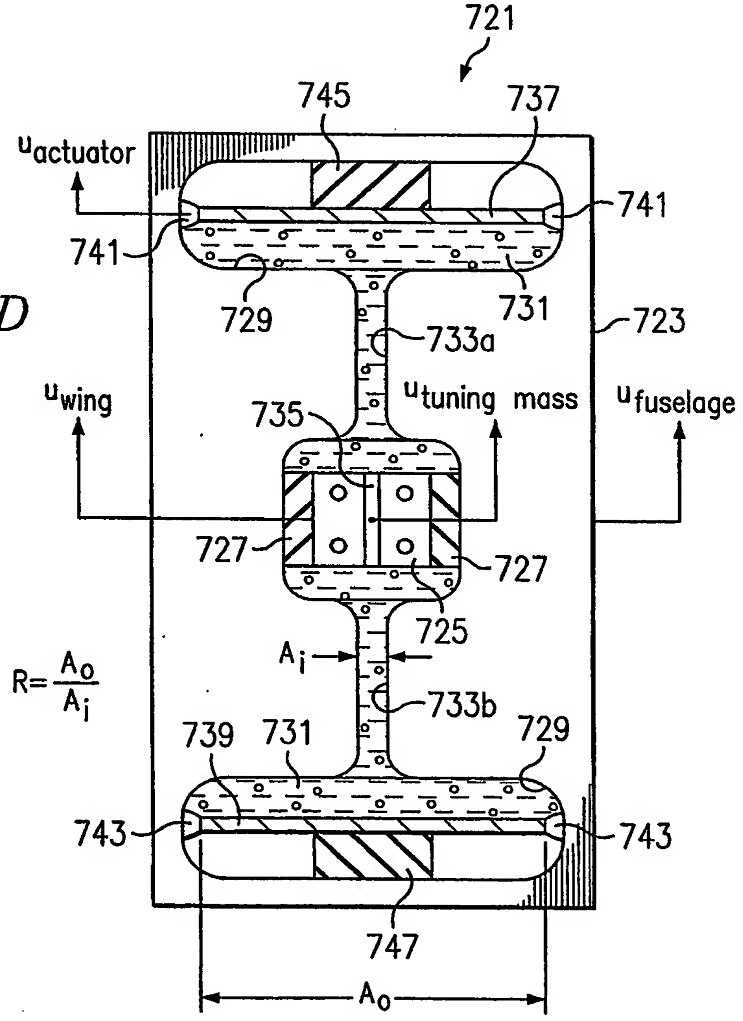

$u_{actuator}$
u_{wing}
$u_{tuning\ mass}$
$u_{fuselage}$
A_i
$R=\frac{A_o}{A_i}$
A_o

FIG. 8

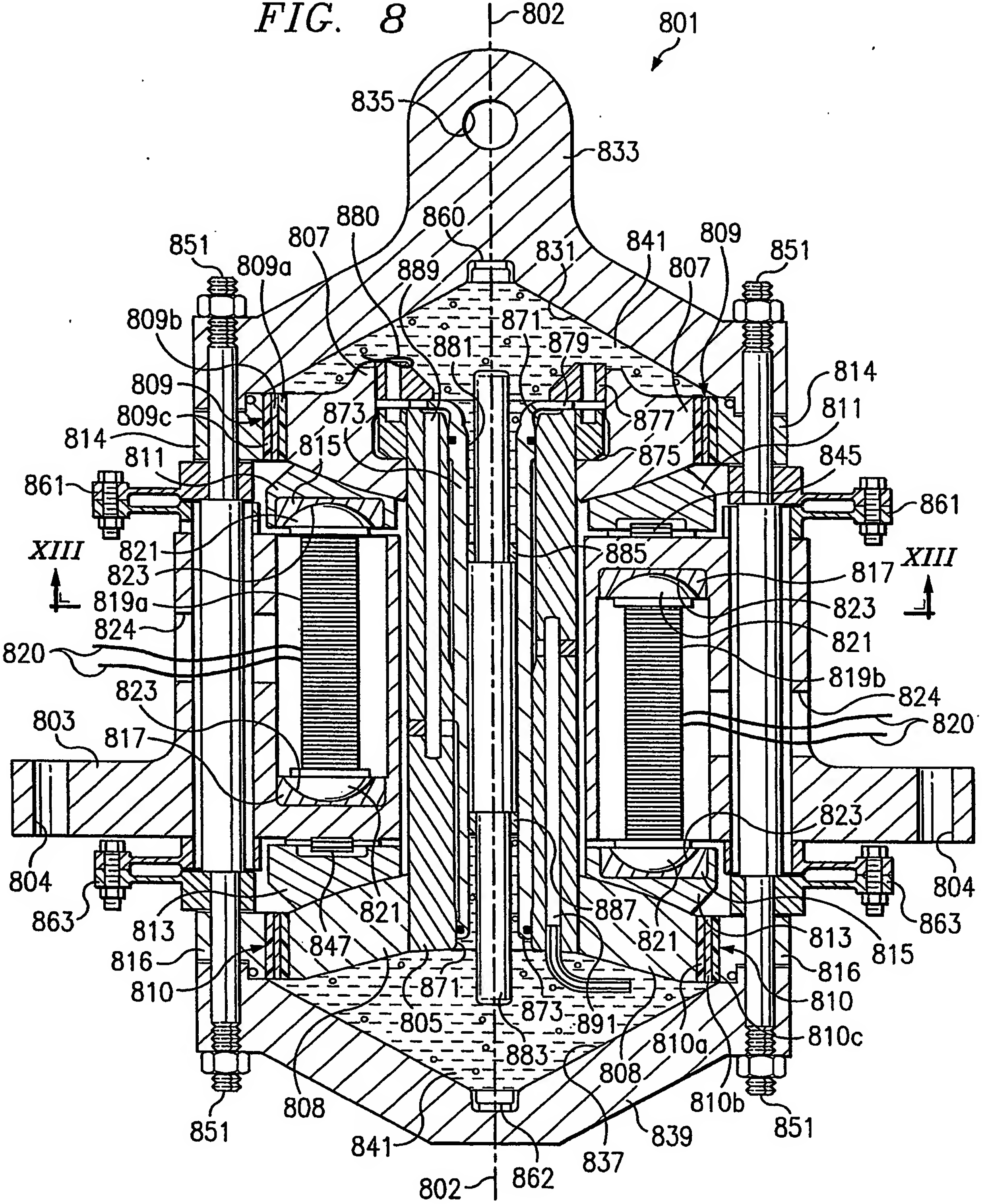

XIII
XIII

FIG. 9

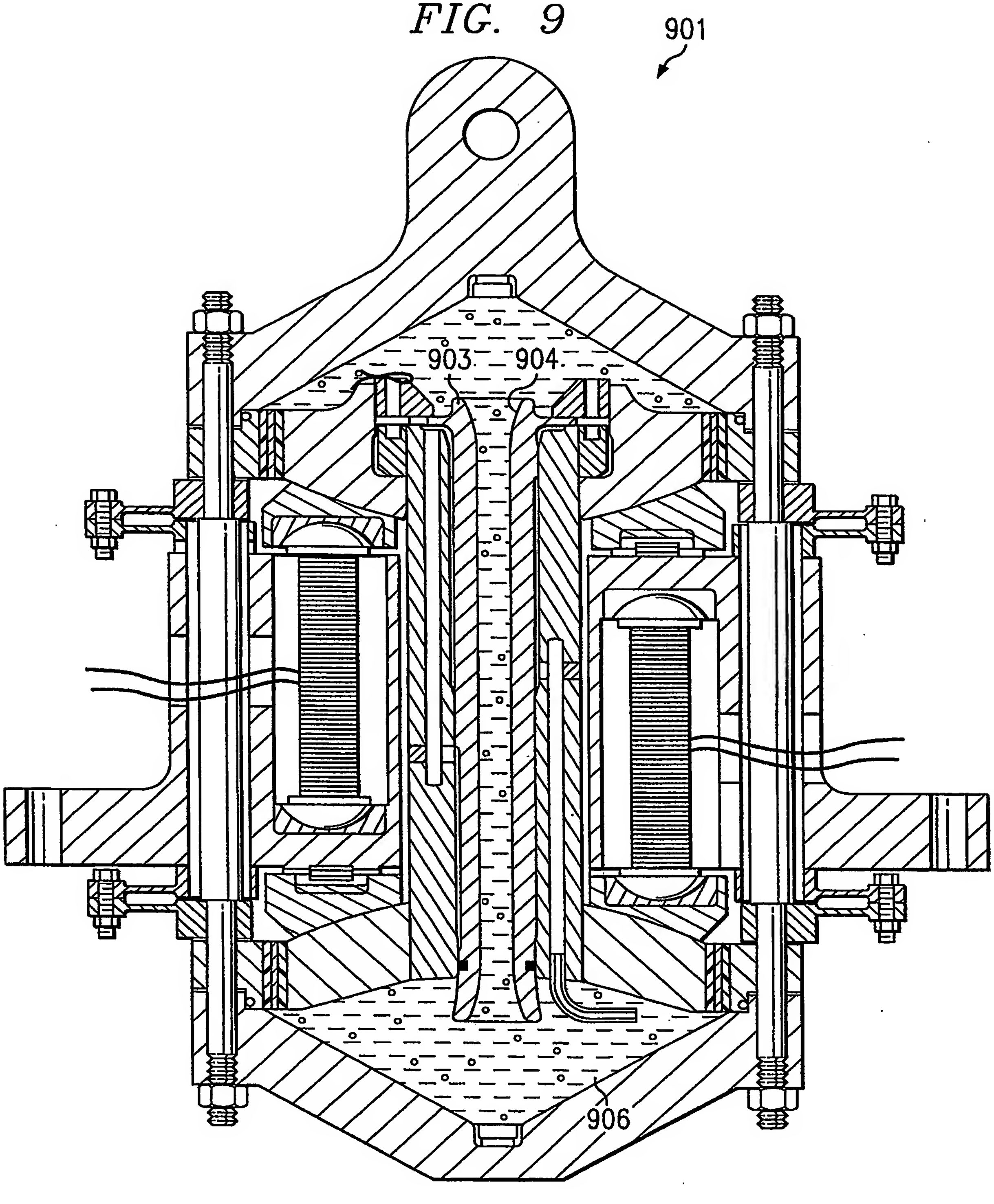

901
903
904
906

FIG. 10

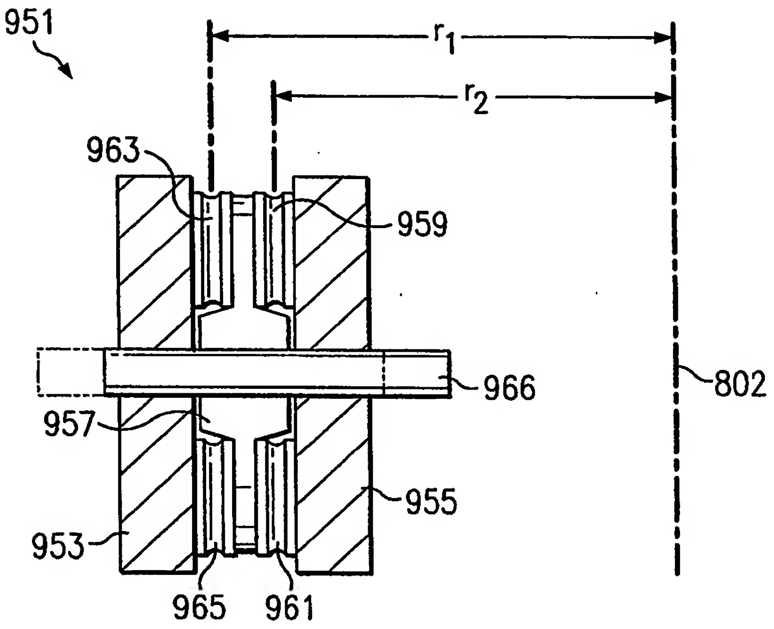

951
r_1
r_2
963
959
966
802
957
955
953
965
961

FIG. 11

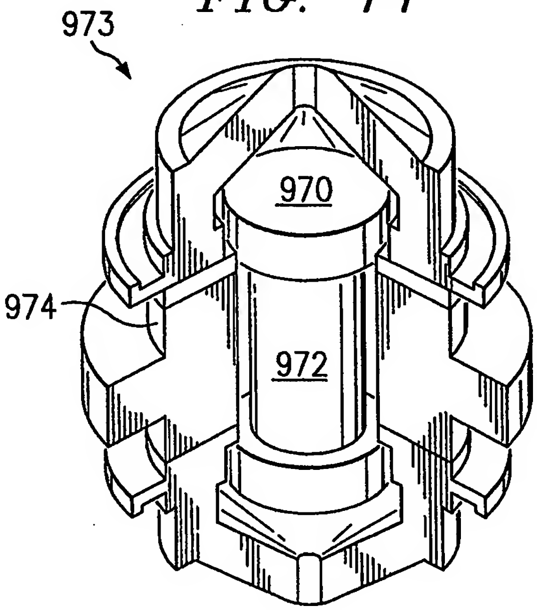

973
970
974
972

FIG. 12

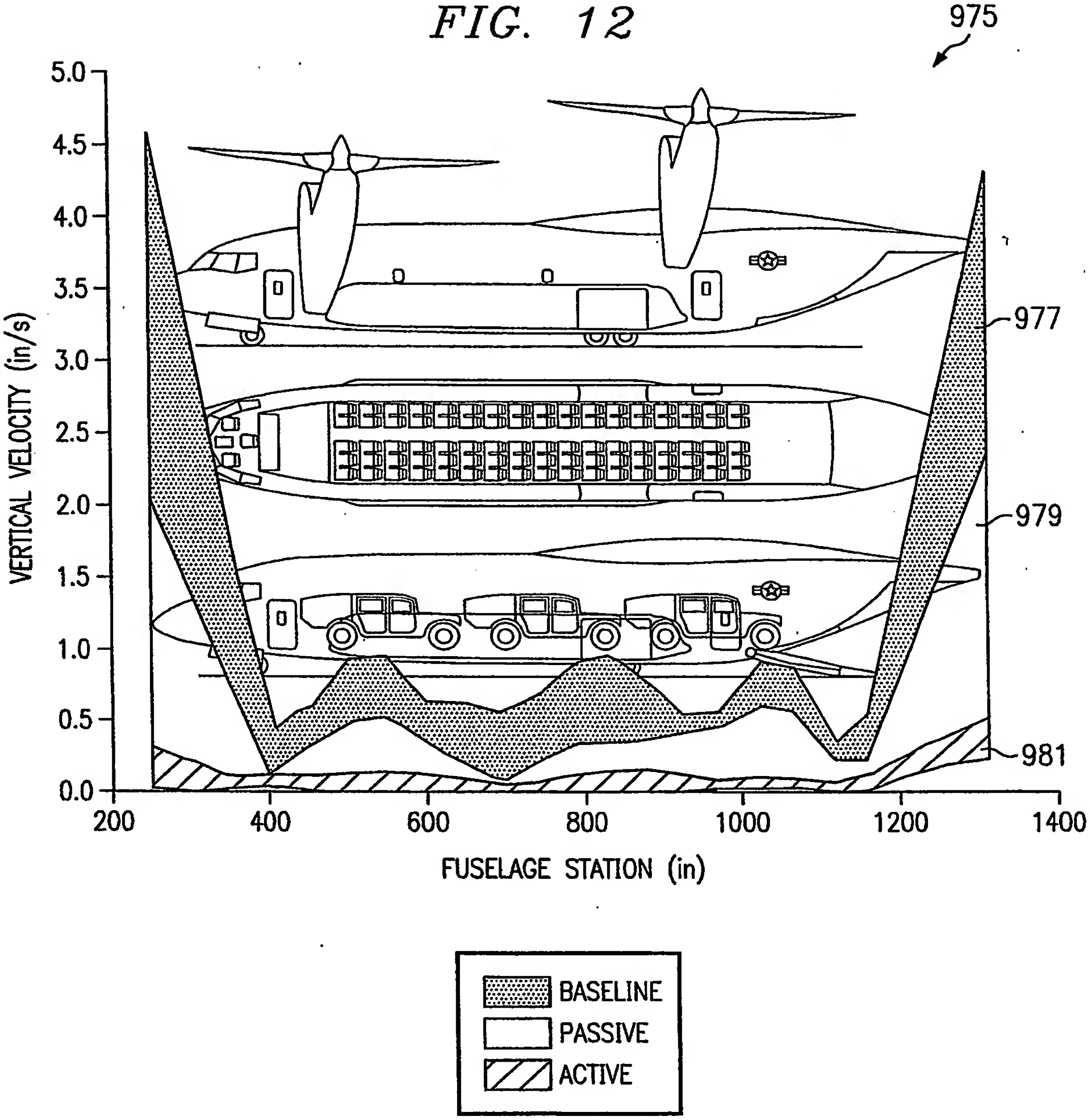

975
977
979
981
VERTICAL VELOCITY (in/s)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200
400
600
800
1000
1200
1400
FUSELAGE STATION (in)
BASELINE
PASSIVE
ACTIVE

FIG. 13

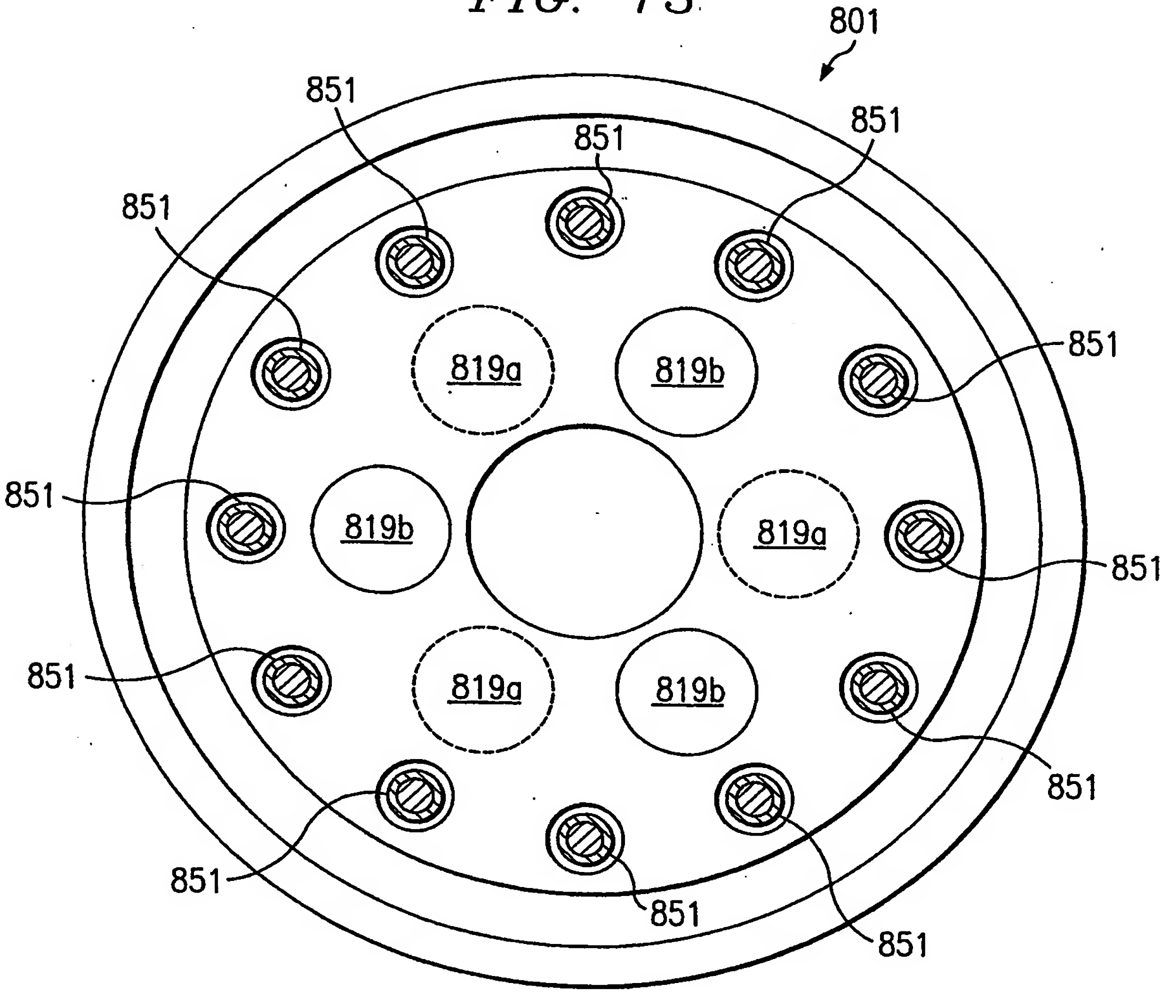
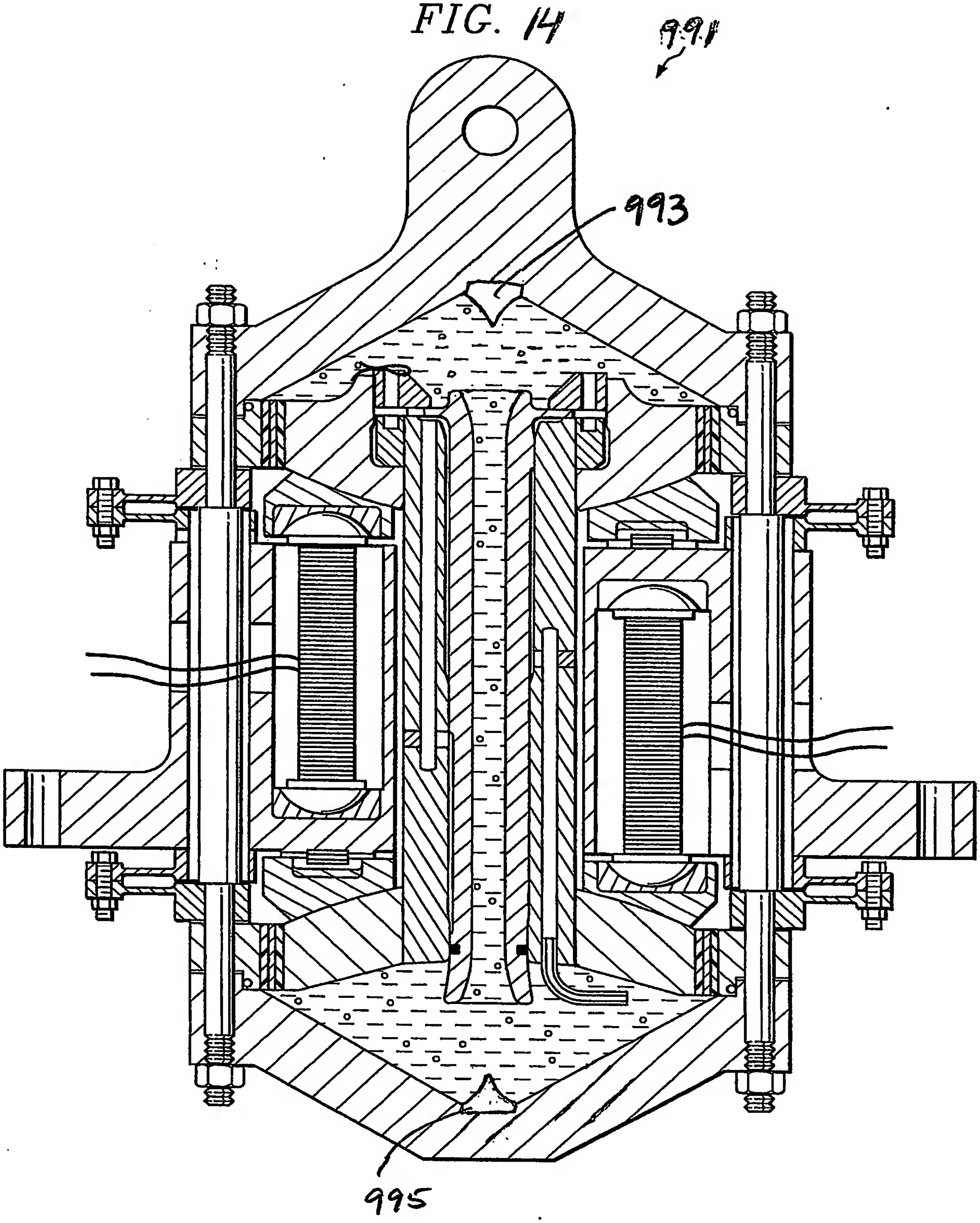


FIG. 14



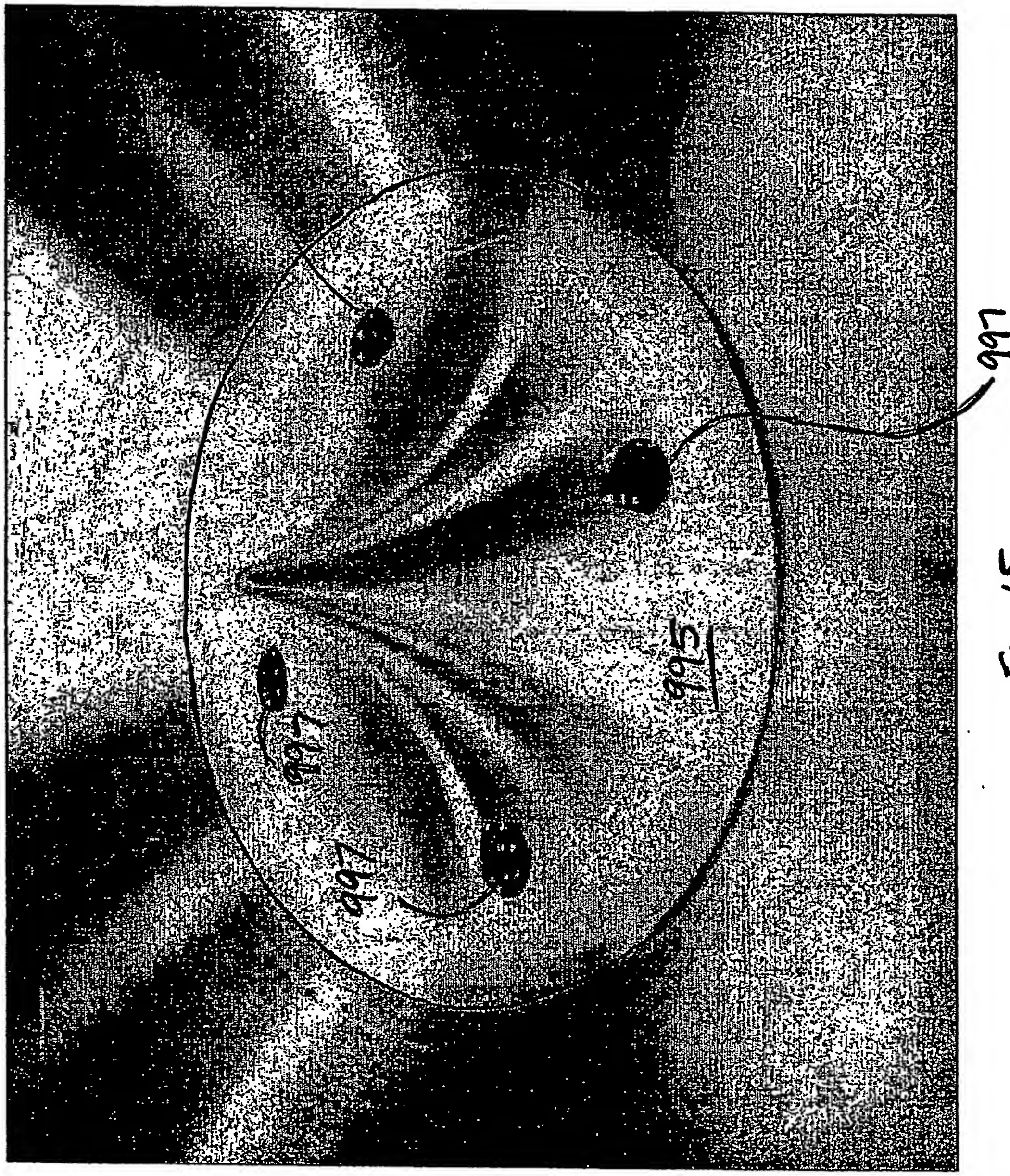

997
995
997
997

Fig. 15

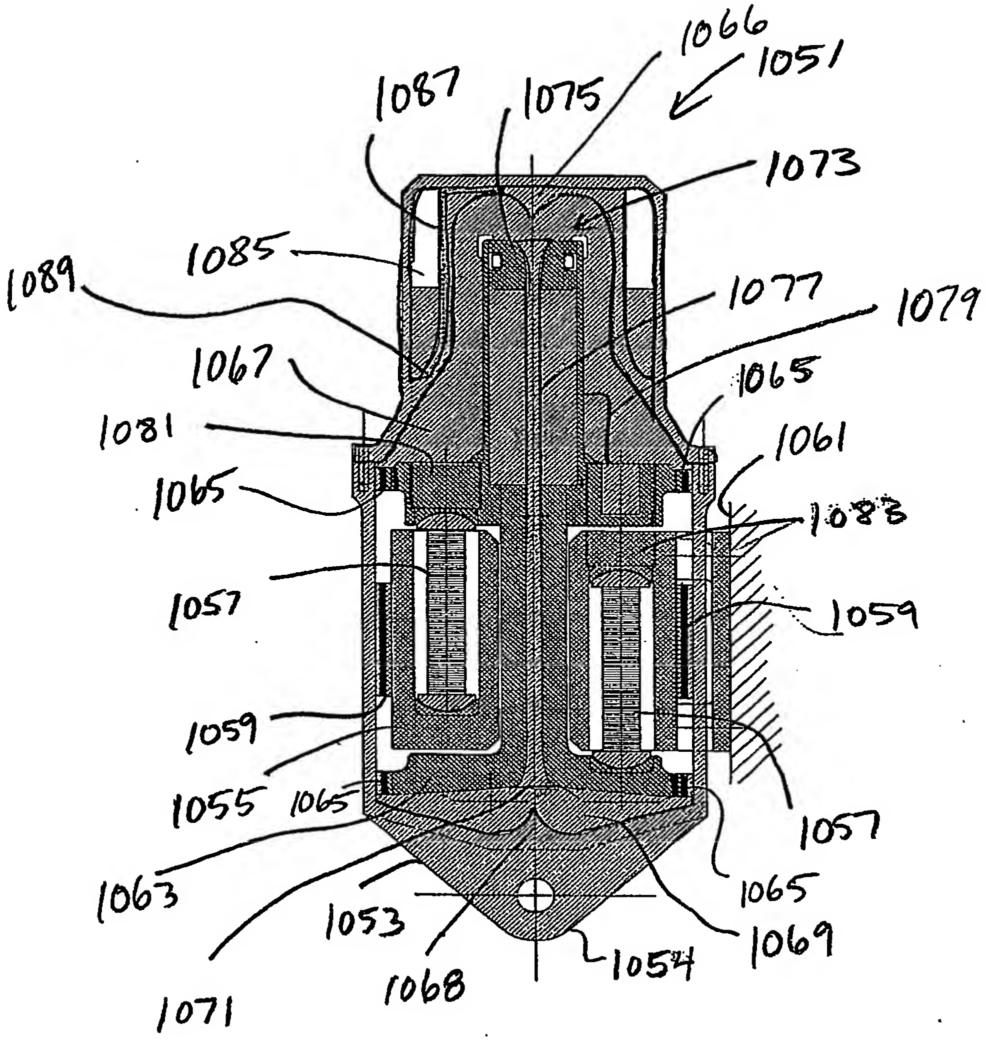


Fig. 16

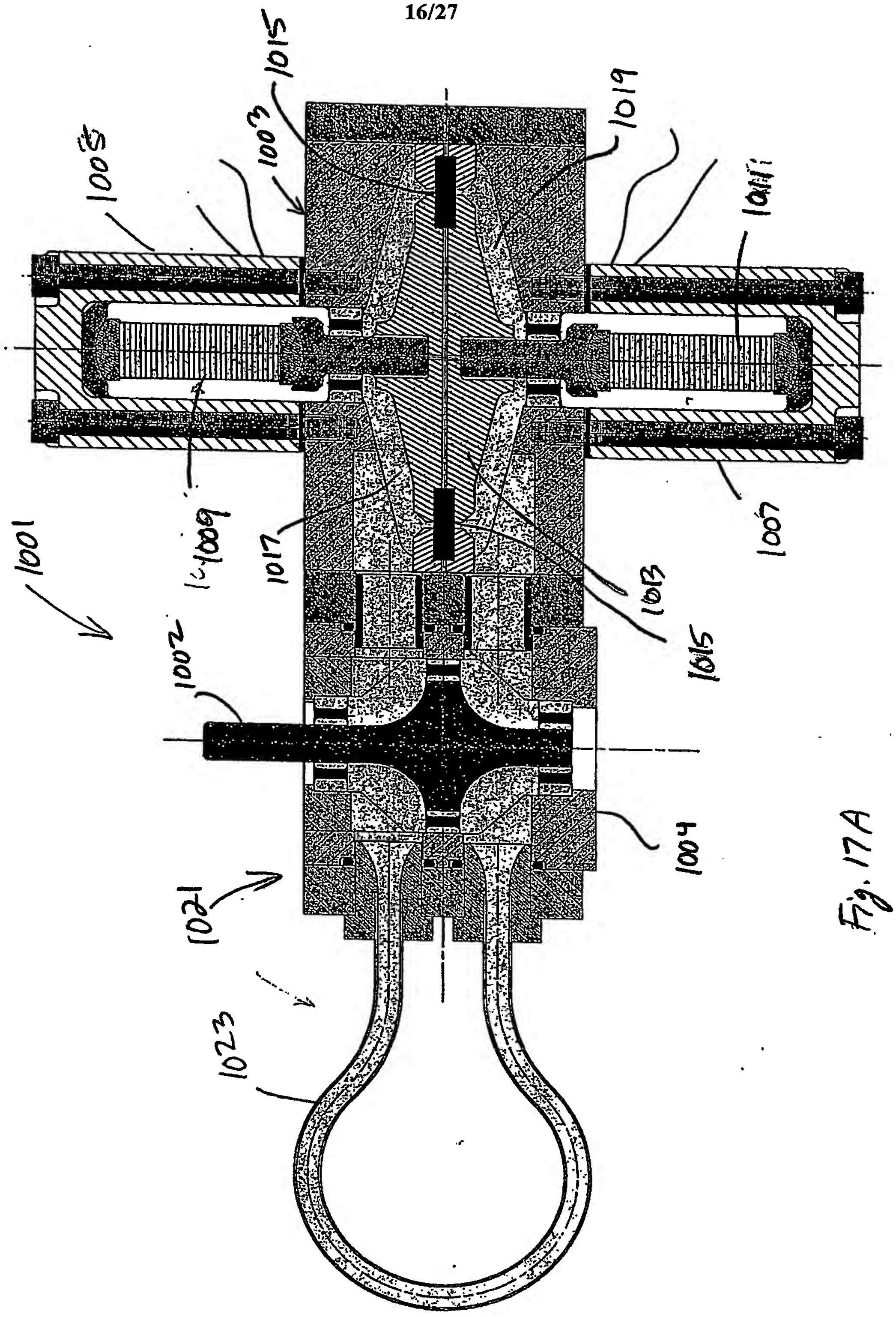


Fig. 17A

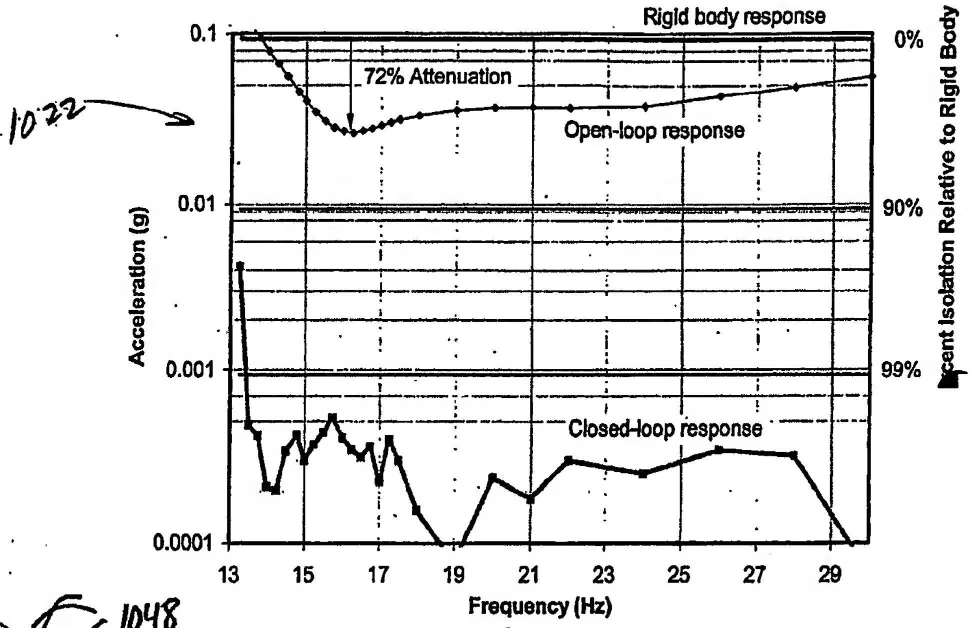


Fig. 17 B

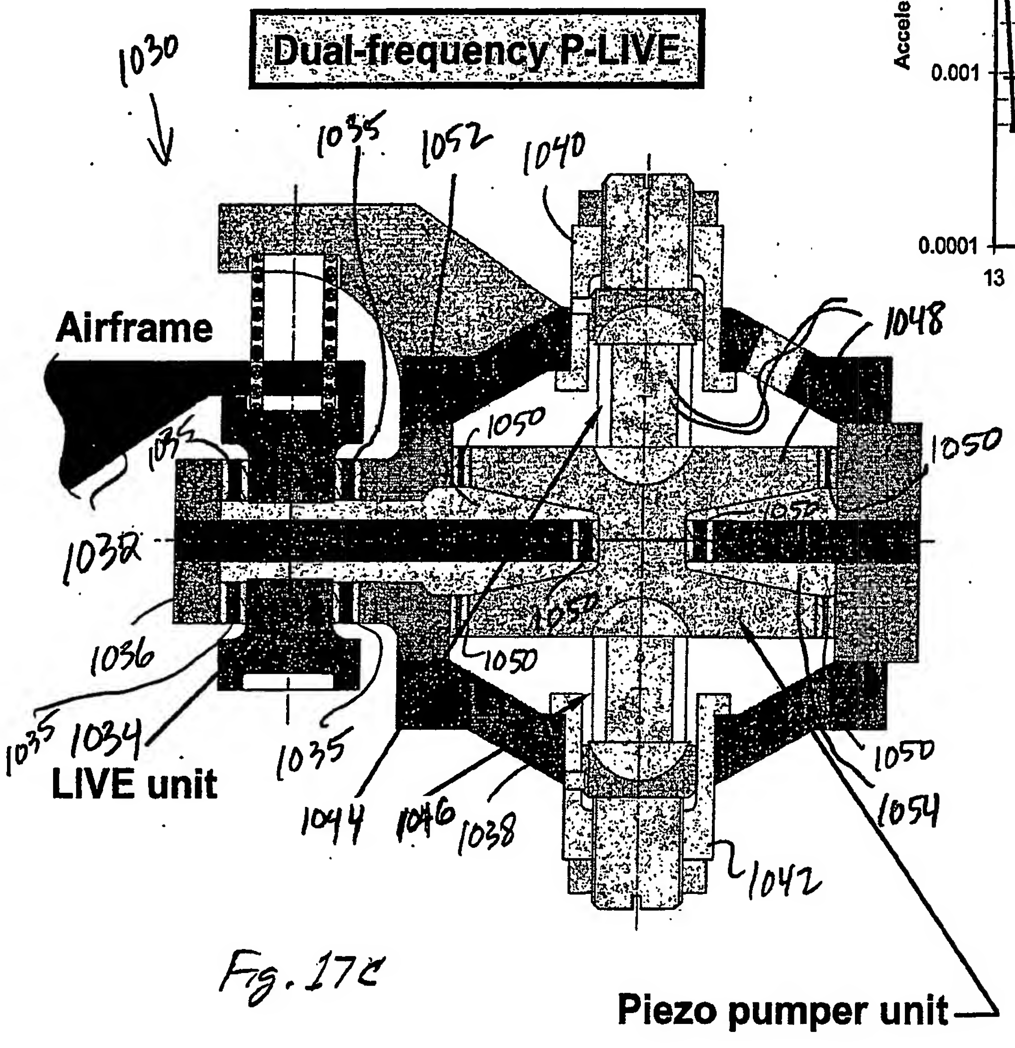

1030
Dual-frequency P-LIVE
Airframe
LIVE unit
Piezo pumper unit
1035
1052
1040
1048
1050
1050
1050
1052
1050
1050
1035
1032
1036
1035
1034
1035
1044
1046
1038
1042
1050
1054

Fig. 17C

Governing Equation for isolation frequency

$$f_{isolation} = \frac{1}{2\pi}\sqrt{\frac{4K\eta g}{R_{LIVE}(R_{LIVE}-1)\pi d_t^2 l_t \rho_t}}$$

Fig. 19A

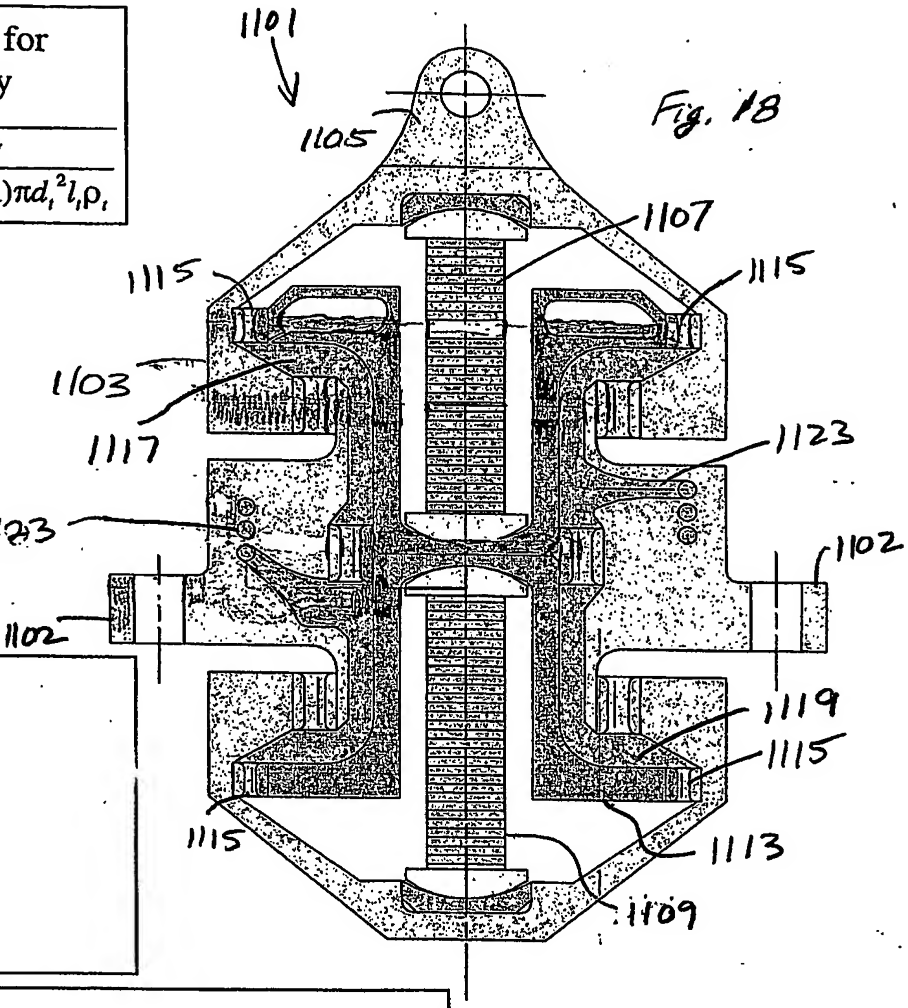

1101
1105
1107
1115
1115
1103
1117
1123
1123
1102
1102
1119
1115
1115
1113
1109

Fig. 18

Fig. 19B

Area ratios

$$R_{piezo} = \frac{(2.1884)^2}{(1.1447)^2} = 3.65$$

Length and number of turns of fluid tuning passage

$$l_t = \frac{4K\eta g}{R_{LIVE}(R_{LIVE}-1)\pi d_t^2 \rho_t (2\pi f_{isolation})^2}$$

$$N = \frac{l_t}{2\pi r_t}$$

Fig 19C

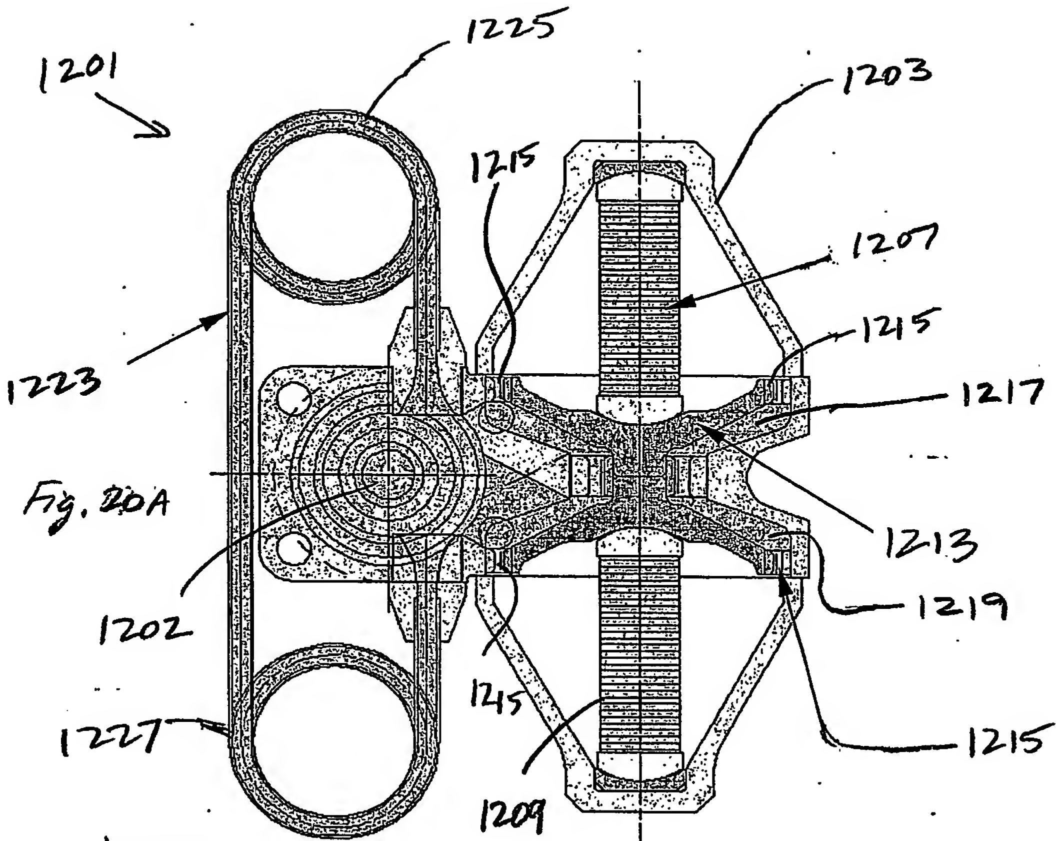

1201
1225
1203
1215
1207
1215
1217
1223
1213
1202
1219
1215
1227
1215
1209

Fig. 20A

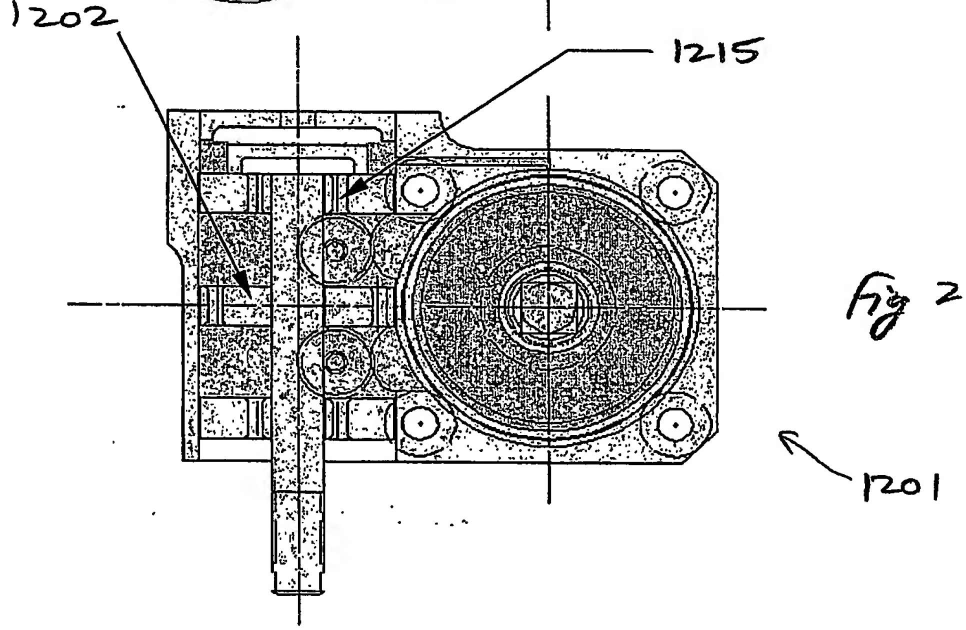

1202
1215
1201

Fig 20B

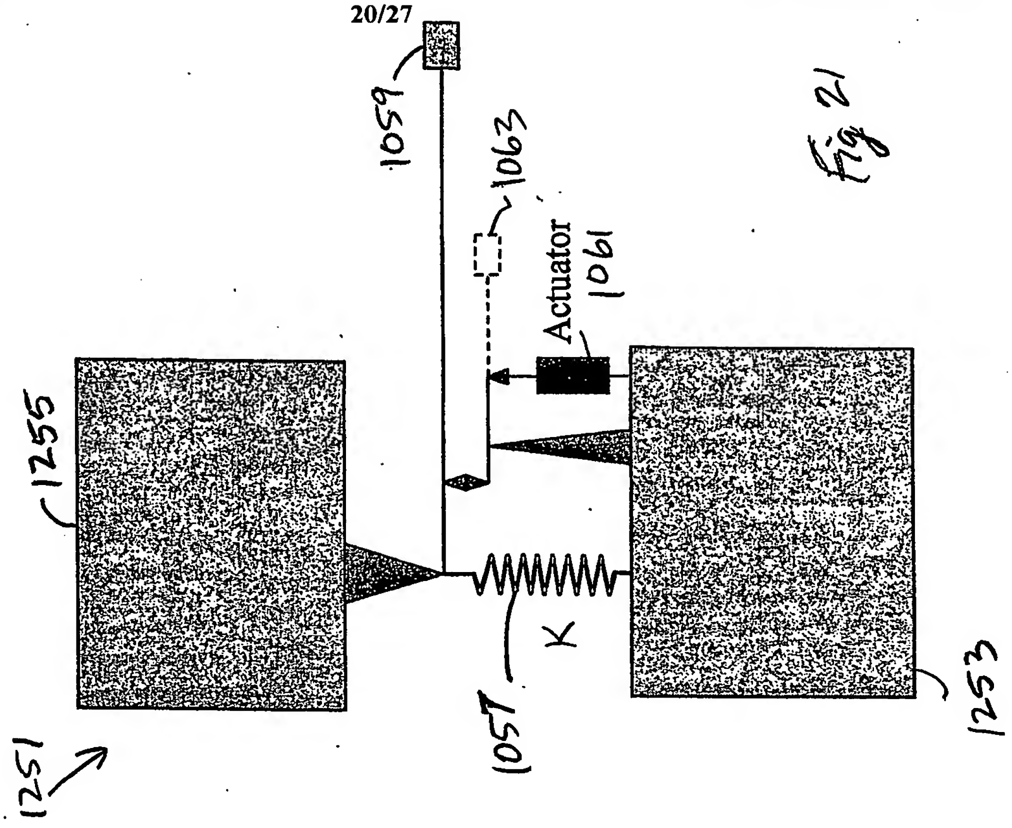

1059
1063
Actuator
1061
1255
1251
K
1057
1253

Fig 21

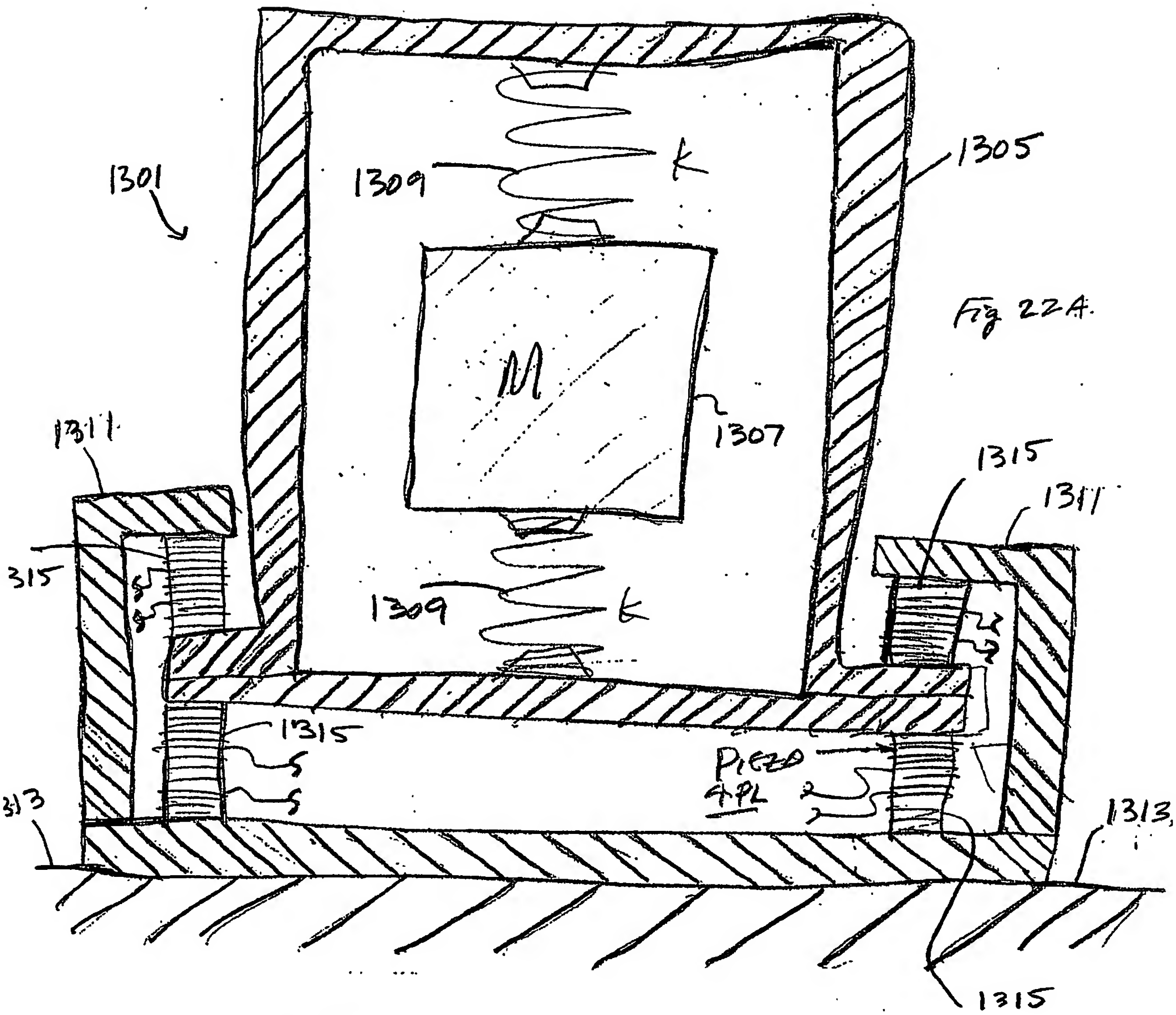

1301
1305
1309
K
M
1307
1311
1315
1311
315
1309
K
1315
Piezo
4PL
313
1313
1315

Fig 22A.

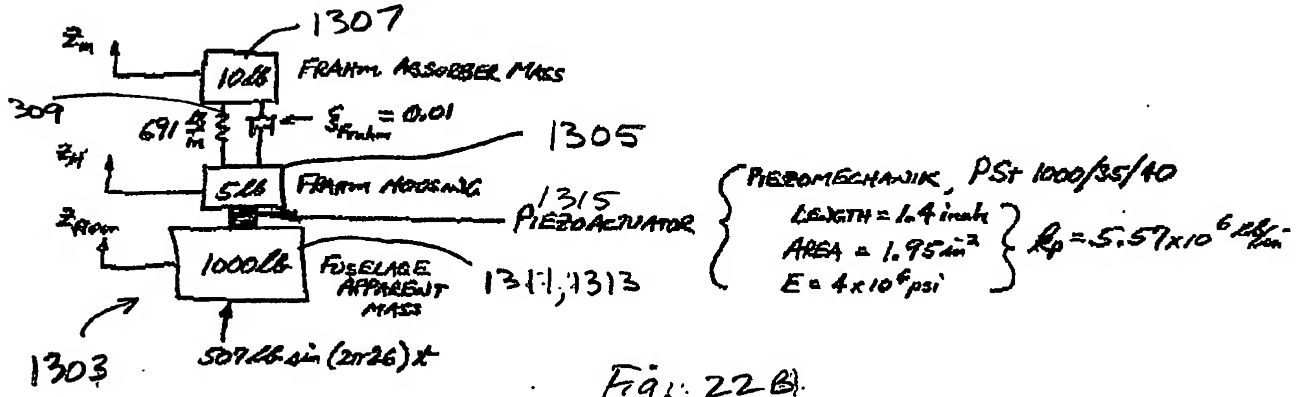

Zm
1307
10 lb
FRAHM ABSORBER MASS
309
691 lb/in
ζFrahm = 0.01
1305
ZH
5 lb
FRAHM HOUSING
1315
PIEZOACTUATOR
Zfloor
1000 lb
FUSELAGE APPARENT MASS
1311, 1313
1303
507 lb sin (2π26)t
PIEZOMECHANIK, PSt 1000/35/40
LENGTH = 1.4 inch
AREA = 1.95 in²
E = 4×10⁶ psi
kp = 5.57×10⁶ lb/in

Fig. 22B

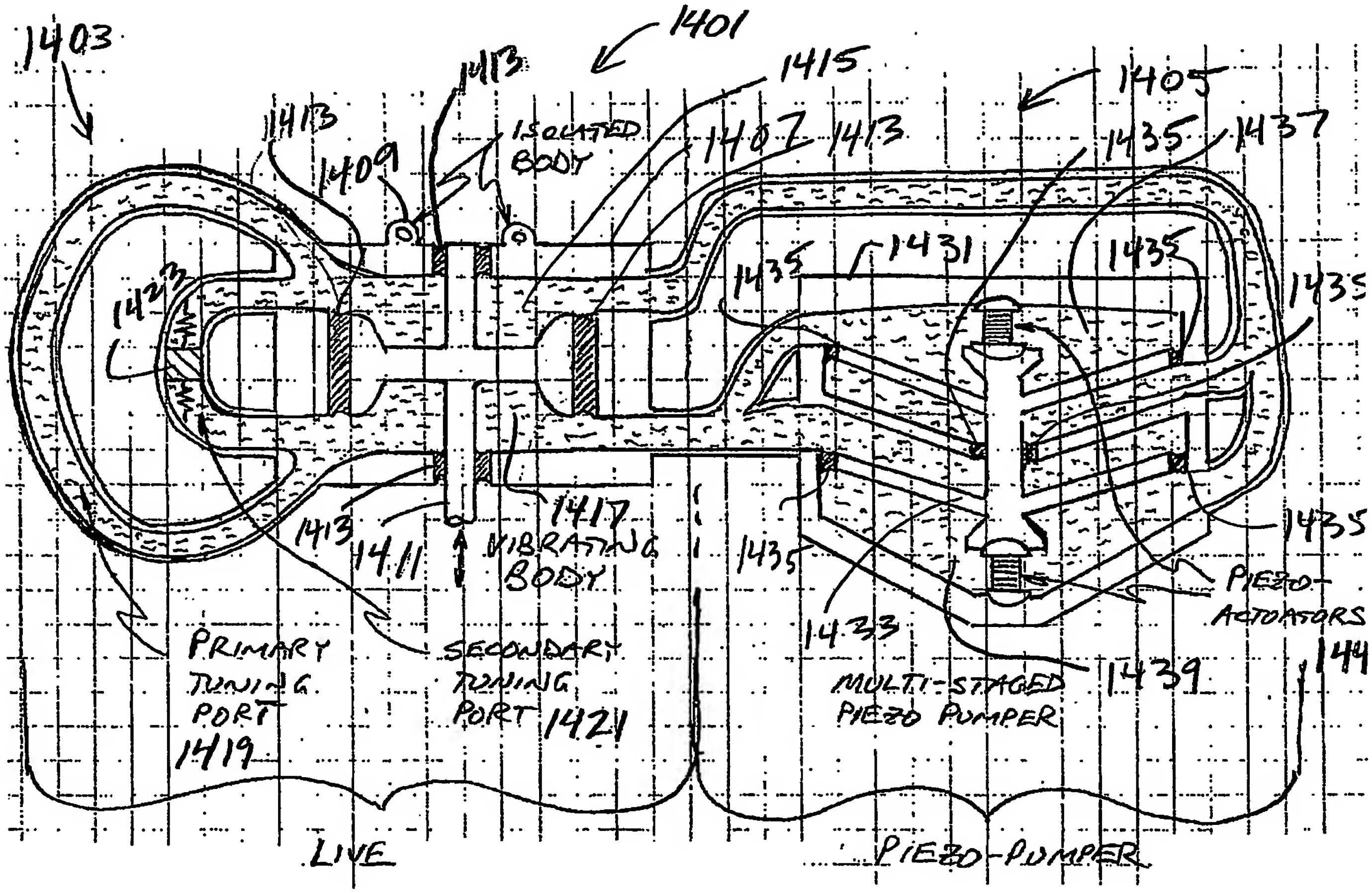

ISOLATED BODY
VIBRATING BODY
PIEZO-ACTUATORS
PRIMARY TUNING PORT 1419
SECONDARY TUNING PORT 1421
MULTI-STAGED PIEZO PUMPER
LIVE
PIEZO-PUMPER

Fig. 23A

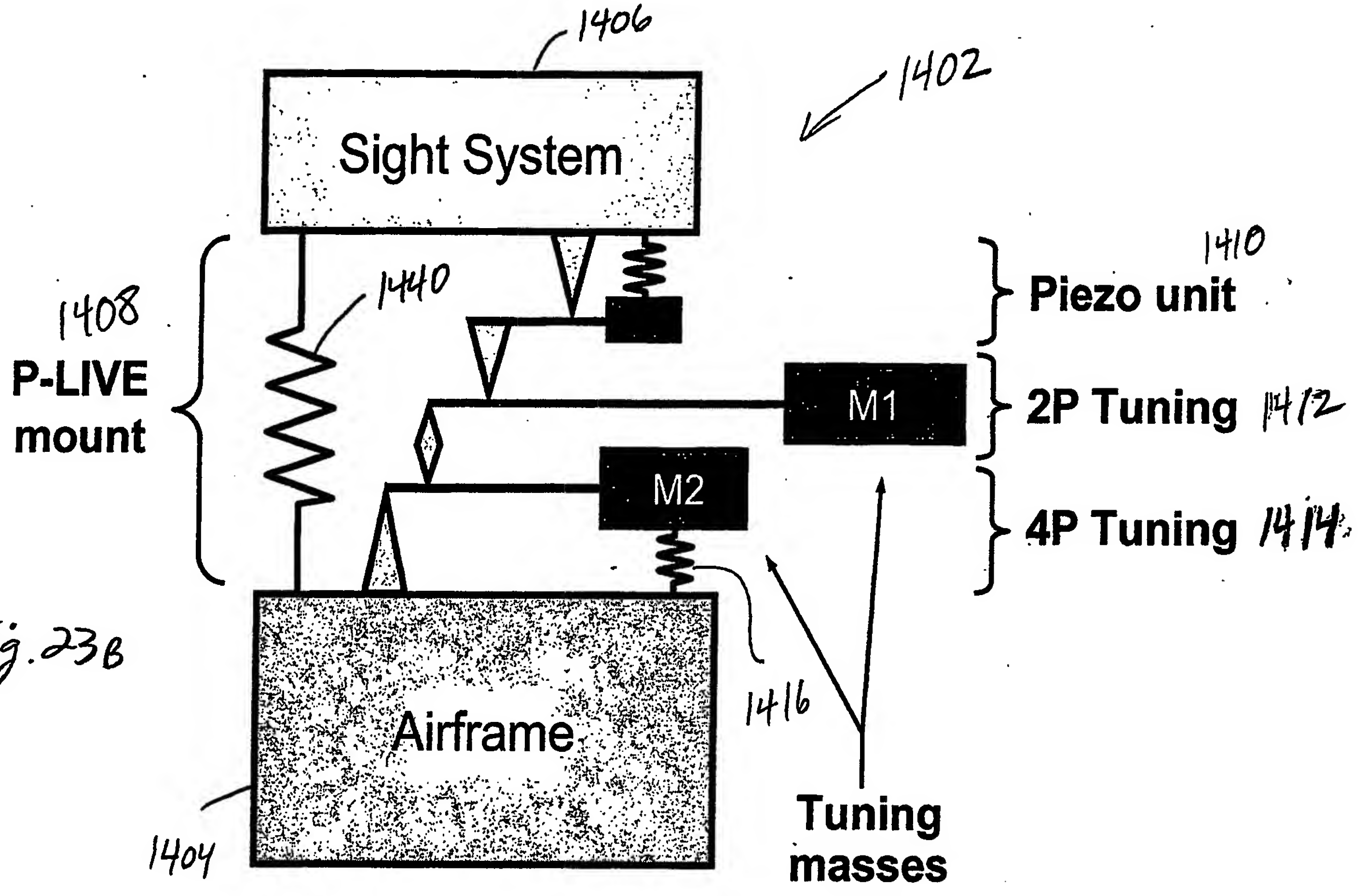

1406
Sight System
1402
1410
Piezo unit
1408
P-LIVE
mount
1440
M1
2P Tuning 1412
M2
4P Tuning 1414
Airframe
1404
1416
Tuning
masses

Fig. 23B

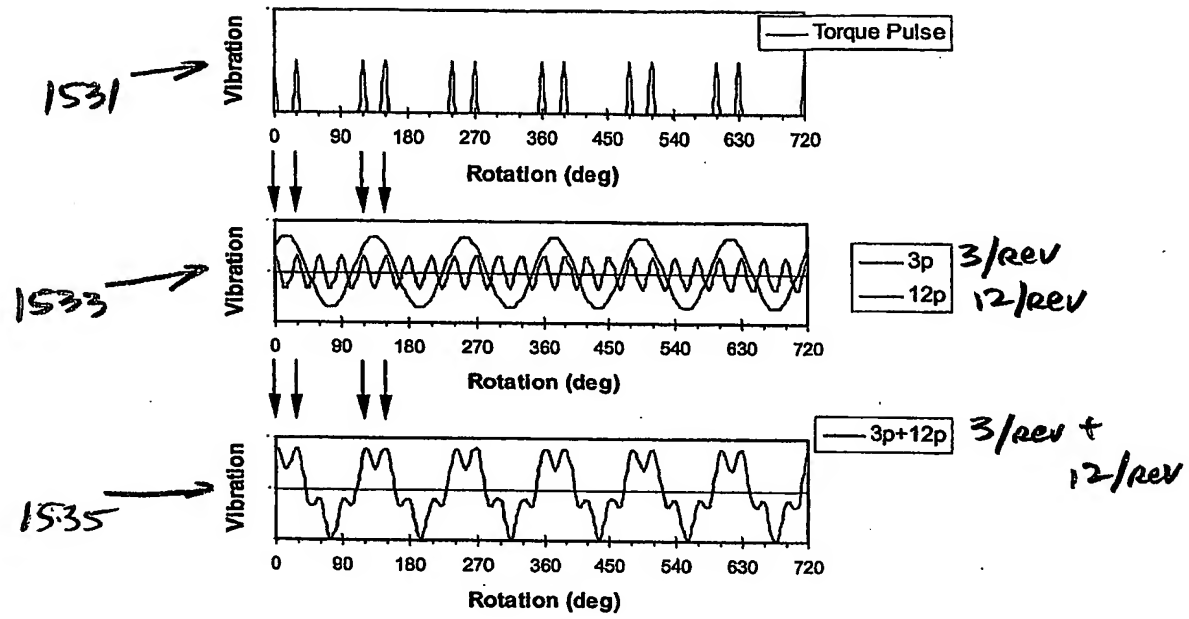

1531
Vibration
Torque Pulse
0
90
180
270
360
450
540
630
720
Rotation (deg)
1533
Vibration
3p
12p
3/rev
12/rev
0
90
180
270
360
450
540
630
720
Rotation (deg)
1535
Vibration
3p+12p
3/rev +
12/rev
0
90
180
270
360
450
540
630
720
Rotation (deg)

Fig 24

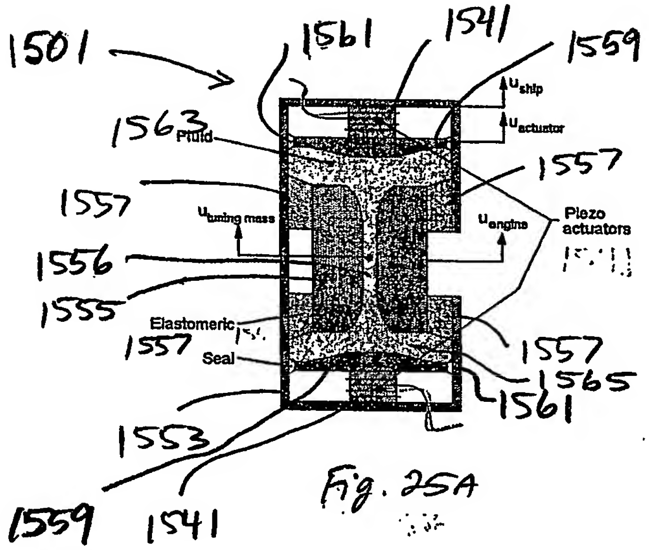

1501
1561
1541
1559
1563
Fluid
u_{ship}
$u_{actuator}$
1557
1557
$u_{tuning\ mass}$
u_{engine}
Piezo actuators
1556
1555
Elastomeric
1557
Seal
1557
1565
1561
1553
1559
1541

Fig. 25A

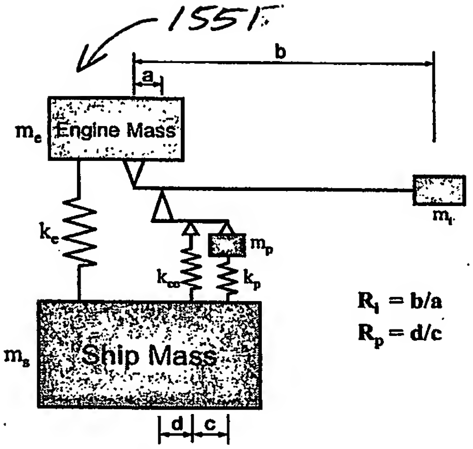

1551
b
a
m_e
Engine Mass
m_t
k_e
m_p
k_{eo}
k_p
m_s
Ship Mass
d
c
$R_t = b/a$
$R_p = d/c$

Fig. 25B

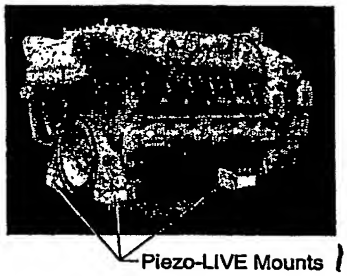

Piezo-LIVE Mounts
1601

Fig. 26C

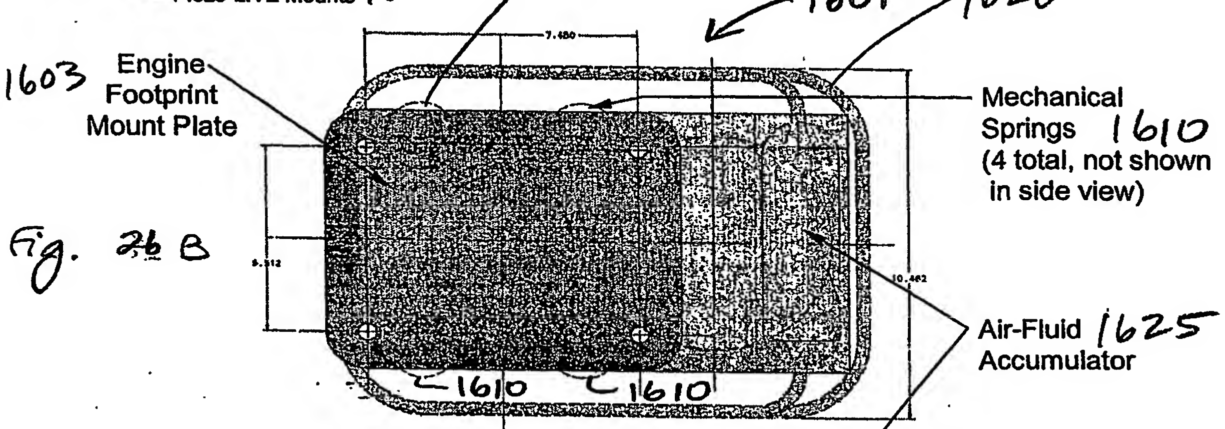

1610
1601
1620
1603
Engine Footprint Mount Plate
7.480
Mechanical Springs 1610 (4 total, not shown in side view)
9.312
10.462
Air-Fluid 1625 Accumulator
1610
1610

Fig. 26 B

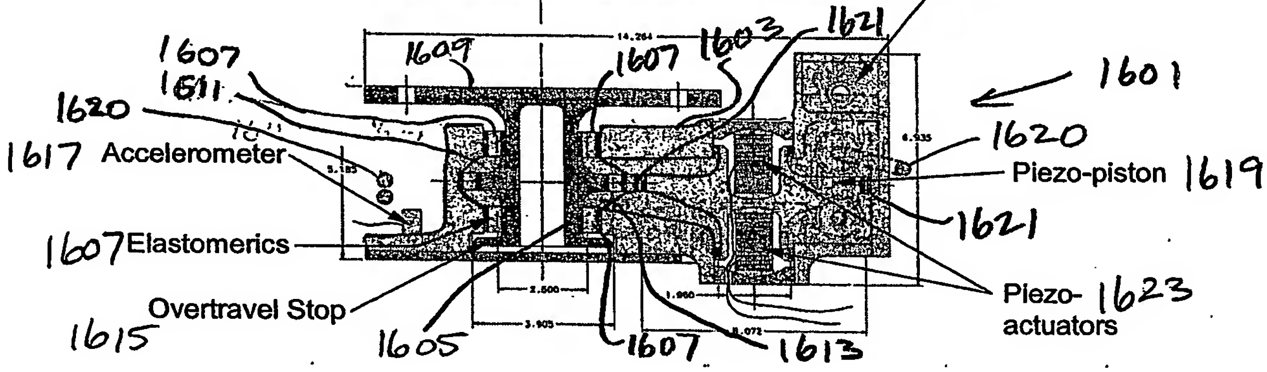

14.264
1607
1611
1620
1617 Accelerometer
1607 Elastomerics
Overtravel Stop
1615
1609
1607
1603
1621
1601
1620
Piezo-piston 1619
1621
Piezo- 1623 actuators
6.935
5.185
2.500
3.905
1.960
1605
1607
1613

Fig 26A

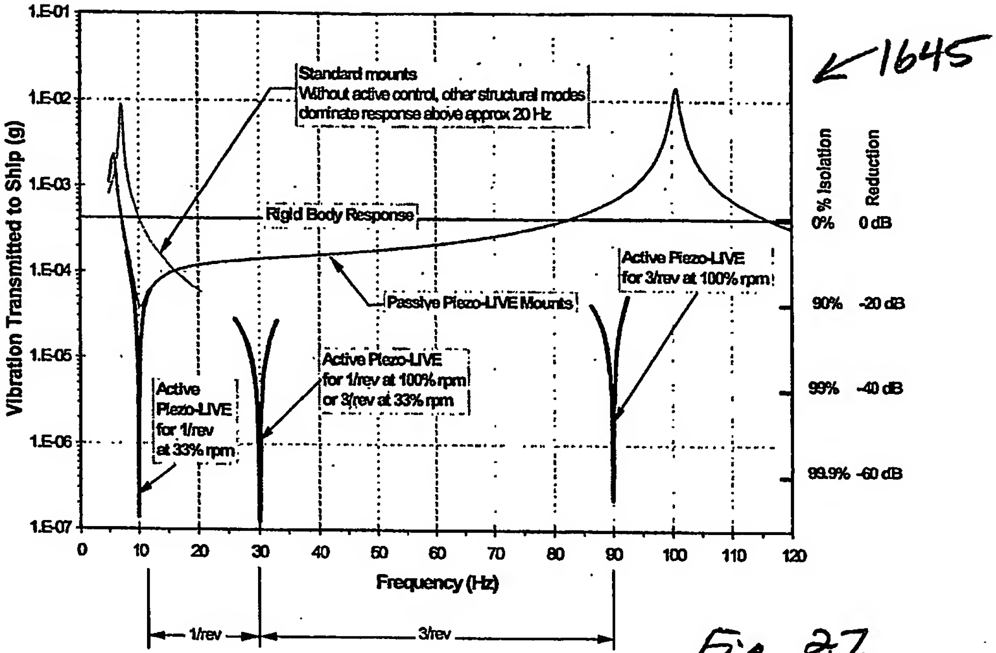

1645
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
Vibration Transmitted to Ship (g)
0
10
20
30
40
50
60
70
80
90
100
110
120
Frequency (Hz)
% Isolation
Reduction
0% 0 dB
90% -20 dB
99% -40 dB
99.9% -60 dB
Standard mounts
Without active control, other structural modes dominate response above approx 20 Hz
Rigid Body Response
Passive Piezo-LIVE Mounts
Active Piezo-LIVE for 3/rev at 100% rpm
Active Piezo-LIVE for 1/rev at 100% rpm or 3/rev at 33% rpm
Active Piezo-LIVE for 1/rev at 33% rpm
1/rev
3/rev

Fig. 27